

Evaluating the Potential Effectiveness of Using Computerized Information Systems to Prevent Adverse Drug Events

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In this study a dynamic computer simulation model is used to estimate the effectiveness of various information systems applications designed to detect and prevent medication errors that result in adverse drug events (ADEs). The model simulates the four stages of the drug ordering and delivery system: prescribing, transcribing, dispensing and administering drugs. In this study we simulated interventions that have been demonstrated in prior studies to decrease error rates. The results demonstrated that a computerized information system that detected 26% of medication errors and prevented associated ADEs could save 1,226 days of excess hospitalization and \$1.4 million in hospital costs annually. Those results suggest that such systems are potentially a cost-effective means of preventing ADEs in hospitals. The results demonstrated the importance of viewing adverse drug events from a systems perspective. Prevention efforts that focus on a single stage of the process had limited impact on the overall error rate. This study suggests that system-wide changes to the drug-ordering and delivery system are required to significantly reduce adverse drug events in a hospital setting.

INTRODUCTION

Adverse drug events (ADEs) during hospitalization are common.¹ An ADE is defined "... as an injury resulting from medical intervention related to a drug."² A recent study of two teaching hospitals found that the rate of ADEs was 6.5 per 100 hospital admissions. Errors were detected at every stage of the process: ordering (56%) transcription (6%), dispensing (4%) and administration (34%).^{2,3} Two recent studies have estimated the costs of ADEs in hospitalized patients. One study at the LDS Hospital in Salt Lake City, Utah estimated the extra length of hospital stay attributable to an ADE was 1.74 days; while the excess cost of

hospitalization was estimated to be \$2,012.⁴ A second study at Brigham and Women's Hospital and Massachusetts General Hospital in Boston estimated the additional length of stay associated with an ADE was 2.2 days; the increase in cost associated with an ADE was \$2,595.⁵ Based on these costs and incidence rates of ADEs, it was estimated that the annual costs attributed to all ADEs at the LDS Hospital are \$1.1 million and \$5.6 million at a teaching hospital in Boston.

Most hospitals rely on voluntary reporting which may result in the detection and reporting of only 10% of ADEs.^{6,7} At the same time the increasing availability of computerized information systems in hospitals makes it possible to develop and implement automated surveillance systems to detect ADEs. An 18 month study at the LDS Hospital found that the traditional reporting system only detected 9 ADEs whereas computerized monitoring of 36,633 patients during the same period detected 731 ADEs.⁸ A second study at Brigham and Women's Hospital found that a computerized information system detected from 53% to 89% of ADEs identified through chart review depending upon the sophistication of the information system.⁹

Results of these studies suggest that efforts to improve quality by reducing errors that result in ADEs may reduce the costs of care.² In the present study, we describe a computer simulation model that can be used to estimate the effectiveness of various information system applications designed to detect and prevent medication errors that result in ADEs. The model was constructed using a systems approach that identifies components of the drug delivery system which make errors more likely to occur and difficult to detect and prevent.³ It predicts the number of errors at each step in the drug delivery system, the number of associated ADEs, the extra number of days of hospitalization and the excess costs of hospitalization attributable to ADEs.

METHODS

Hospital Setting

The initial study was performed in a private teaching hospital.¹⁰ Ninety-one percent of medication orders are written by physicians. Almost all of these orders are then transcribed and entered into the computerized hospital information system by hospital ward clerks. Physicians enter 9% of their orders directly into the system bypassing the ward clerks. Orders are printed out in a centralized pharmacy where the drugs are dispensed and transported to the wards for administration.

Data Collection

The quality assurance records for the previous 12 months in the central pharmacy were used to obtain baseline data on the number of medication errors that were detected prior to this study. In order to collect data on medication order errors, hospital pharmacists verified every drug order written by physicians on two medical-surgical units during the day and evening shift for a 12 week period. A total of 6,966 drug orders were reviewed for this study. When an error was detected, the pharmacist completed a form that identified the prescribing physician, unit secretary and/or nurse involved with the order, the nature of the incident, and the action taken to correct the error. Hospital pharmacists were also available for consultation on the units during the day and evening shifts. They recorded information about all consultations.

Analysis

A classification scheme was developed to classify the types of medication errors and their severity.¹¹⁻¹³ During the 12 month baseline period, pharmacists detected only 48 prescription errors or one error per 1,000 drug orders. During the 12 week study period when all drug orders on the hospital units were reviewed, pharmacists detected 227 errors. This represented a rate of 32 errors per 1,000 orders.

In general, 83% of the errors were made in transcribing the physicians' orders and entering them into the medical information system. Physicians made errors in writing prescriptions in 14% of the cases. The other 3% of the errors were in dispensing and administering medications.

Medication errors were classified by their potential severity. On both hospital units, 74% of the errors were classified as problem orders. These orders lacked

information about dosage, route or frequency of drug administration; involved minor spelling or transcription errors, etc. However, there was little or no potential for increased adverse effects in patients. Eighteen percent of the errors were potentially significant. These prescriptions involved omitted drugs; duplicate orders; or the wrong information concerning dosage, route, or frequency. If not detected and corrected, these prescriptions could have resulted in adverse effects on the patient. About 6% of the medication errors were potentially serious. These errors might have resulted in serious toxic reactions or inadequate therapy for a serious illness. The last category of medication errors were potentially lethal and could have resulted in the death of the patient. Two percent of the errors were classified into this category.

THE COMPUTER SIMULATION MODEL

A dynamic computer simulation model was constructed to model hospital medication errors using STELLA, a graphically-based software package.^{14,15} The model is shown in Figure 1. It is assumed that an average of 4060 medication orders are written on 14 hospital medical-surgical units each week. The majority of orders are entered into the hospital information system by unit secretaries. The medications are dispensed in the central pharmacy. Once the medications are delivered to the unit, they are administered by an RN.

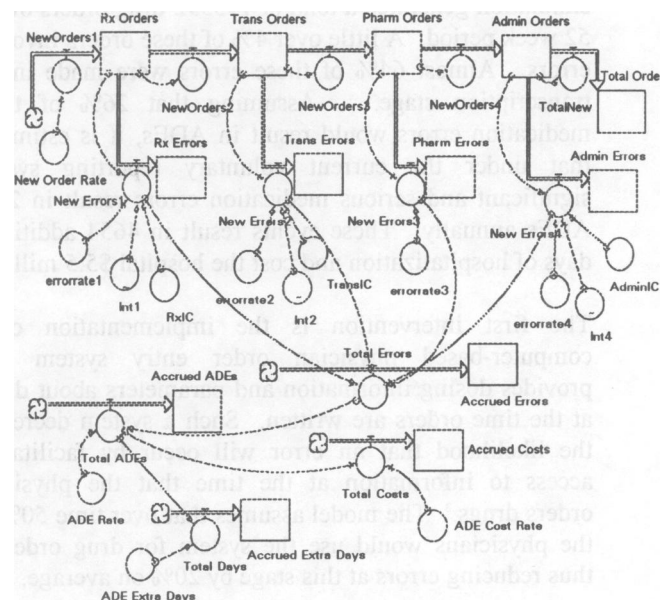


Figure 1. Systems Model of the Drug Ordering and Delivery System

Based on an earlier study, it was assumed that error rates at each stage of the process were variable and distributed normally. Means and standard deviations for error rates are shown in Table 1.¹⁰ Two estimates were made of the number of ADEs and associated excess days of hospitalization and costs. The highest estimate assumed that 26% of the medication errors that involved omitted drugs; wrong information concerning dosage, route, or frequency; or prescriptions that could have resulted in serious toxic reactions or inadequate treatment would have resulted in ADEs if not detected. The low estimate assumed only the 8% of drug errors that were potentially fatal if undetected would have resulted in ADEs.

Table 1. Error Rates per 1,000 Medication Orders

Stage	Mean	SD
Prescription	4.6	2.0
Transcription	27.0	10.0
Dispensing	4.3	2.0
Administration	5.7	2.0

RESULTS

The model has been used to simulate the drug ordering and delivery system on fourteen medical-surgical units in a teaching hospital. In this study we simulated interventions that have been demonstrated in prior studies to decrease error rates. Tables 2 and 3 show the results of a baseline run and runs that simulate potential information system applications. The baseline simulation generated a total of 195392 drug orders over a 52 week period. A little over 4% of these orders involved errors. Almost 64% of these errors were made in the transcription stage. Assuming that 26% of these medication errors would result in ADEs, it is estimated that under the current voluntary reporting system significant and serious medication errors result in 2115 ADEs annually. These events result in 4654 additional days of hospitalization and cost the hospital \$5.5 million.

The first intervention is the implementation of a computer-based physician order entry system that provides dosing information and parameters about drugs at the time orders are written. Such a system decreases the likelihood that an error will occur by facilitating access to information at the time that the physician orders drugs.³ The model assumes that over time 50% of the physicians would use the system for drug ordering thus reducing errors at this stage by 20% on average.

This intervention by itself failed to significantly reduce the overall error rate. While this intervention resulted in about a 21% reduction in prescription errors, total errors were only reduced by about 5%. The model predicts over 2,000 ADEs resulting in 4412 excess days of hospitalization costing over \$5 million annually.

One of the most effective ways of reducing errors is to simplify the elaborate multistage system of drug ordering and delivery. The earlier study found that over 80% of errors were made in transcribing physicians' written orders by ward clerks. Anderson and others¹⁶ demonstrated that by encouraging physicians to develop

Table 2. Medication Errors by Stage of the Drug Ordering and Delivery System

Run	Rx	Trans	Disp	Admin	Errors	Orders
BL	948	5220	868	1099	8136	195392
1	747	5063	853	1050	7714	195286
2	1016	4050	881	1151	7099	195245
3	947	5503	805	352	7609	195288
4	747	4055	836	354	5993	195196

personal order sets, the percentage of medical orders directly entered into the medical information system could be significantly increased in a teaching hospital. An earlier computer simulation estimated that elimination of the need for transcription of medical orders could reduce errors by as much as 40%.¹⁷ One study at Brigham and Woman's Hospital found that if all medical orders were entered on-line by physicians, 58% of all adverse events were identifiable.² The second intervention simulated assumes that if 50% of the drug orders were directly entered by physicians the error rate would be reduced by about 30%.

Table 3. ADEs and Associated Extra Costs and Days of Hospitalization

Run	ADE	ADE	LOS	LOS	Cost	Cost
	Low	High	Low	High	Low	High
BL	636	2115	1400	4654	1652136	5489752
1	666	2005	1466	4412	1730304	5205135
2	554	1845	1220	4061	1439332	4790148
3	567	1978	1249	4352	1473817	5133856
4	482	1558	1060	3428	1251290	4044135

The second intervention involved encouraging physicians to enter their own orders directly into the hospital information system. The model estimated that this would

reduce transcription errors by 22%. However, the total number of errors was only reduced from 4.2% to 3.6%. Overall excess days of hospitalization would be reduced by about 600 days and costs by about \$700,000.

The third intervention that was simulated involved computer surveillance of adverse drug events. One such system that was implemented with the HELP system at the LDS Hospital in Salt Lake City, Utah relied on computerized surveillance to detect potential ADEs based on clinical data such as certain laboratory tests, discontinuation of medications, decreases in dosages and ordering of antidotes.⁸ Daily reports of ADEs were then provided to the hospital staff. The investigators report that over 85% of ADEs were detected once the hospital system was implemented. The third simulation assumes that the introduction of such a system would result in a reduction of errors when drugs are administered to a rate of 0.9 per 1000 orders.

The result of the simulation of this intervention is shown in Tables 2 and 3. The model predicts that the implementation of a computer-based surveillance system would reduce medication errors at the administration stage by 68%. However, the overall effect on the error rate is small, a reduction of about 6%. The model estimates that this intervention would only reduce excess hospital days by 300 and annual costs by \$355,896.

The final analysis simulates the effects of utilizing the hospital information system to simultaneously implement all three interventions. The model suggests that errors would be reduced at the prescription, transcription, and administration stages of the drug ordering and delivery system. It is estimated that a comprehensive information system could detect and prevent over 2,000 medication errors a year. Overall ADEs would be reduced by 26%. The final implementation of an information system would have a substantial effect reducing excess hospital days by 1,226 and saving the hospital \$1.4 million in related costs annually.

DISCUSSION

This study estimated the effectiveness of several computerized information system applications designed to detect and prevent medication errors that result in ADEs. The cost-effectiveness of these systems needs to be documented since current voluntary reporting systems for ADEs detect only a fraction of such events.^{2,6,7,9} The voluntary reporting system in the hospital that we studied detected only 1 medication error per 1,000 drug orders.

Our study revealed an error rate of 32 per 1,000 drug orders. It was estimated that over 8,000 medication errors occur on 14 medical-surgical units each year. Based on error rates from an earlier study of medical-surgical units at the teaching hospital and published estimates of the effects of ADEs on length of stay and hospital costs, a computer simulation model estimated that, under the voluntary system, ADEs annually result in from 1400 to 4654 days of extra hospitalization and from \$1.6 to \$5.5 million in excess hospital costs. The lower estimate of the effects of medication errors assumes that only the 8% of errors that might have led to serious toxic reactions, inadequate treatment, or death of the patient would have resulted in ADEs. The higher estimate assumes that the additional 18% of medication errors that involved omitted drugs, duplicate orders, or incorrect information also would have led to ADEs.

The model indicates that an implemented information system designed to detect and prevent ADEs could save 1,226 days of hospitalization and \$1.4 million in hospital costs annually even if it only prevented 26% of medication errors. These savings reflect only direct hospital costs. They do not include the additional costs of outpatient care, disability and malpractice awards associated with ADEs. A recent study used the outpatient costs of ADEs to a managed care provider to project that these costs nationwide may be as high as \$76.6 billion.¹⁸

This study demonstrates the importance of viewing adverse drug events from a systems perspective. Errors occur at every stage of the drug-ordering and delivery system. Many result from systems failures and are not detected by the typical hospital self-reporting system. Moreover this study indicated that system-wide changes to the process are required to significantly reduce medication errors in a hospital setting. Preventive efforts that focus solely on a single stage of the process have limited impact on the overall error rate.

We conclude that the traditional medical approach to medication error prevention that relies on individual detection and voluntary reporting is reactive and largely ineffectual.¹⁹ If hospitals are to reduce medication errors that lead to ADEs and associated unnecessary costs and days of hospitalization, they will have to recognize the multiplicity of reasons that errors occur at each stage of the drug delivery system. Computerized information systems are an important means of detecting errors in time to take corrective action to prevent ADEs. The results of this study suggest that information systems are

potentially a cost-effective means of preventing ADEs in hospitals.

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